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Diversity and biomass of understory vegetation which might increase fire risk in Mount Rinjani National Park, Lombok Island, Indonesia

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Abstract. *Metananda AA, Suhubdy, Mertha IG, Soekardono, Afrianto WF,* Ar NH. *2025. Diversity and biomass of understory vegetation which might increase fire risk in Mount Rinjani National Park, Lombok Island, Indonesia. Asian J For 9: 67-74.* Human activities in the grassland surrounding Mount Rinjani National Park (MRNP), Lombok Island, Indonesia are prevalent, increasing the susceptibility to fires during the dry season. This study assessed the diversity and biomass of understory species which might enhance the risk of fires in the MRNP. Data collection on species diversity was carried out through exploration (non-plot) and creation of 120 sampling plots in Sikur and Sembalun Sub-district. In total, there were 263 species of the understory plants were identified, comprising 71% herbs, 26% shrubs, and 3% lianas. Poaceae and Asteraceae had the largest number of genus and species with the dominance of pioneer species *Themeda triandra*, suggesting that the grasslands in MRNP have not yet reached climax. This species was among the most preferred natural grasses for grazing cows at the study location, indicating intricate relationship between local communities and grassland ecosystem in the MRNP. Over a span of two years, the dry biomass in the area can reach a thickness of 10 cm, with an estimated weight of 5.7 Mg ha^{-1}. The accumulation of high amount of dry biomass poses high risk of fires. The findings of this study offer a substantial foundation for comprehensive interventions in ecosystem management and forest fire risk mitigation, as well as supporting more planned and sustainable conservation efforts.

Keywords: Ecosystem, herbs, lianas, pioneer, shrubs

INTRODUCTION

Annual forest fires result in significant losses in various sectors (Thoha et al. 2022). In ecological aspect, the impacts of fires include the loss of biodiversity and air pollution, adversely affecting air quality and human health. In terms of economics, fires influence agriculture, tourism, and the livelihood of residents. Apart from human-induced, fires might be triggered by natural causes including lightning, particularly cloud-to-ground lightning strikes (Tacconi and Ruchiat 2006) which typically occur during the dry season (Bond 2019). In the Indonesian context, forest fires are more often caused by human activities, such as land clearing for agricultural activities especially during the dry season and El Niño periods (Edwards et al. 2020). However, fires initiated by human activities tend to have more severe and unpredictable consequences (Alvarado et al. 2017). Fires caused by human activity are more challenging to control due to their irregular distribution and the often-inaccessible locations where they occur. Factors influencing forest fires include climate, weather, fire behaviors (i.e., intensity, wildfire circumstance, and spread), and biomass in the form of vegetation type which serves as fuel (Loehman et al. 2014). Post-disturbance ecosystems, such as those affected by wildfires, often retain biological legacies that influence recovery (Swanson et al. 2011).

Savannas account for 30 percent of net terrestrial primary production and the majority (~50-70 percent) of the annual global fire area (Lehmann et al. 2014). In savanna ecosystems, fires significantly impact soil nutrient conditions, altering the availability of essential elements like nitrogen and phosphorus (Nghalipo et al. 2019). Apart as a form of disturbances, fires might serve as a regeneration process that maintains the balance of natural ecosystems (Afrianto et al. 2017, 2020). Fires in savanna ecosystem facilitate the regeneration of grasses (Moritz et al. 2014). Grasslands are influenced by abiotic components such as fire, which produce feedback on soil and plant properties (Reinhart et al. 2016; Werner et al. 2021). At the beginning of the rainy season, plant species in the burned area turn green faster than those in unburned areas, demonstrating that fires in the savanna can maintain grassland condition (Kral et al. 2024). Fire intensity has been found to enhance the resilience of nitrogen utilization, accelerating the recovery of species diversity, including dominant plant species. Thus, fire intensity influences species divergence in savannas (Song et al. 2019).

Savanna generally has sparse tree cover with extensive grasses and shrubs, thus creating hotter, drier and windy microclimates which facilitate fires (Hoffmann et al. 2012). In the savanna ecosystem of Mount Rinjani National Park (MRNP), Lombok Island, Indonesia, the incidence of fires fluctuates annually (Sutomo and van Etten 2018). A key factor influencing savanna fire regimes is the composition of grasses that serve as fuel, with their characteristics significantly affecting fire behavior (Simpson et al. 2022). According to Sutomo et al. (2021) demonstrated distinct floristic differences between savanna and forest and between savanna and the boundary while noting similarities between forest and the boundary; however, environmental data revealed separation solely between savanna and forest. Previous studies in the MRNP primarily focused on the diversity of flora along hiking trails, forested areas, and species diversity boundaries (Mansur et al. 2016; Sutomo et al. 2021).

The relationship between understory vegetation and wildfire risk is complex, as various species exhibit differing flammability characteristics influenced by their biomass and ecological context (Neary et al. 1999). Understory vegetation and biomass contribute to wildfire risk, particularly in pine flatwoods, where greater biomass and flammability characteristics increase ignitability, sustainability, and combustibility, facilitating wildfire spread and necessitating firewise planning for wildland-urban interface homes (Behm et al. 2004). Studies indicate that areas with significant understory growth post-wildfire can lead to increased fire recurrence due to the accumulation of fuels (Coppoletta et al. 2016). This study assessed the diversity of understory species and the biomass-related factors contributing to fires in the MRNP.

MATERIALS AND METHODS

Study area

The study was conducted in the Mount Rinjani National Park (MNRP) area and its surrounding communities, specifically in villages directly bordering the park (Figure 1). The study locations were selected purposively by considering community activities in the grasslands/shrublands and fire-prone areas within the national park from year to year. Mount Rinjani National Park, Lombok Island, West Nusa Tenggara province, Indonesia is a nature conservation area designated based on the Minister of Forestry Decree Number SK. 298/Menhut-II/2005, dated August 3, 2005, with a designated area of 41,330 ha. The MRNP area is geographically located between 116°17'30"E-116°33'30"E and 8°17'30"S-8°33'00"S. Administratively, MRNP spans three regencies: North Lombok District (12,357.67 hectares or 29.9%, comprising two districts and 16 villages), Central Lombok District (6,819.45 hectares or 16.50%, comprising two districts and five villages), and East Lombok District (22,152.88 hectares or 53.60%, comprising 10 districts and 17 villages). This study focused on two specific sub-districts, Sikur (78.27 km²) and Sembalun (217.80 km²), chosen as representative locations for the regional divisions within MRNP.

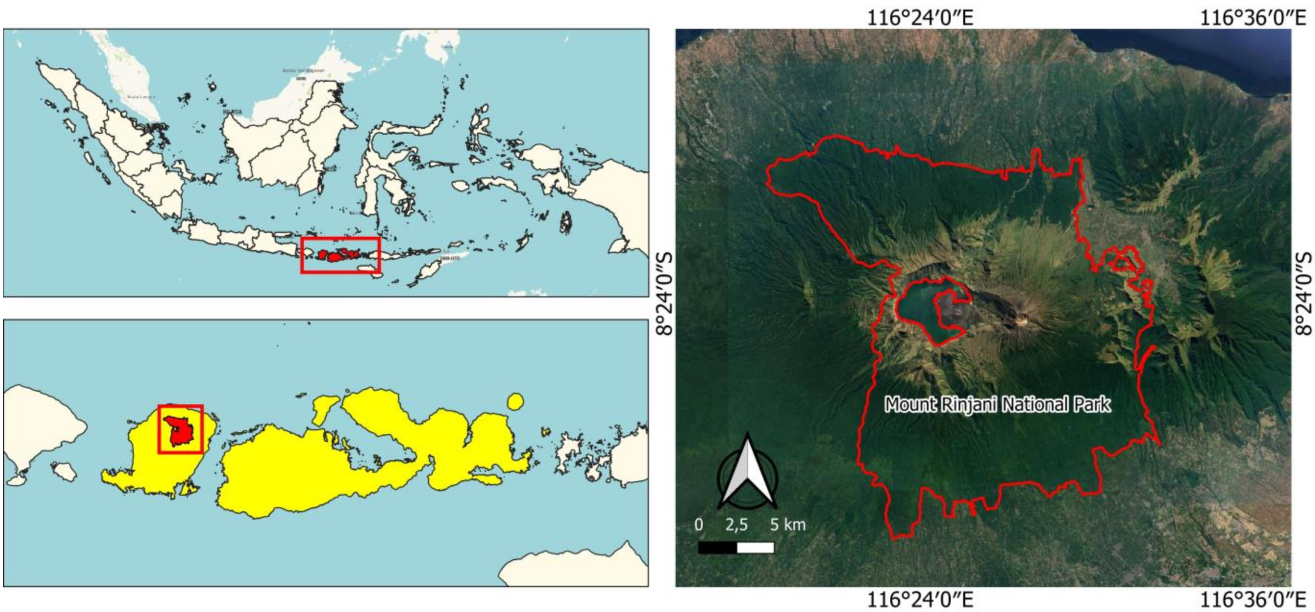

Figure 1. Map of the Mount Rinjani National Park (MRNP), Lombok Island, West Nusa Tenggara Province, Indonesia

The determination of grassland locations to study was based on the interpretation of satellite imagery, which was subsequently verified through field observations. To assess vegetation diversity, multiple plots were established in representative areas within the MRNP. The species-area curve was utilized to determine optimal plot size. A 1 × 1 m square sample plot (SP) was used to record the number of identified plant species, and a second SP was added with twice the size of the first SP until no additional new species were discovered (species addition <5%) (Kusmana 1997). The total plots were 120 plots. Sample plots were placed using random sampling, which is deemed suitable for homogeneous study locations and vegetation. Another method of identifying the list of understory species in the MRNP was to explore the entire national park area. This data was obtained during the current limited time and includes the justified results of previous explorations conducted by researchers in the MRNP.

Procedures

To analyze the potential of litter biomass as fire fuel, a double plot method was employed. The plots, measuring 1 × 1 m, were consistent in size with those used in the species diversity survey. All understory vegetation within the plots was cut and weighed to determine its fresh weight. Similarly, litter within the plots was collected and weighed separately. The plants were then separated into stems and leaves to measure their total wet weight. Subsamples of 100 g were taken from each stem and leaf of the understory plants (if the total weight was less than 100 g, the entire sample was used as the subsample) and dried in an oven for 2 × 24 hours at 80°C.

Data analysis

Vegetation data were collected to assess the importance of the understory obtained at the research location. the following formulas were used for vegetation analysis purposes based on Mueller-Dumbois and Ellenberg (1974).

Density of plant species (D):

$$\mathrm{D} = \frac{\text{Number of individuals of all types}}{\text{Area of all sample plots}}$$

Relative Density (RD):

$$\mathrm{DR} = \frac{\text{Density of a species}}{\text{Density of all species}} \text{ x } 100\%$$

Frequency of plant species (F):

$$\mathrm{F} = \frac{\text{Number of sampled areas where species occured}}{\text{Number of total sampled areas}}$$

Relative Frequency (RF):

$$\mathrm{FR} = \frac{\text{Frequency of a species}}{\text{Frequency of all species}} \text{ x } 100\%$$

Coverage (C):

$$\mathrm{C} = \frac{\text{Number of vegetation cover of all types}}{\text{Area of all sample plots}}$$

Relative Coverage (RC):

$$\mathrm{RC} = \frac{\text{Vegation Cover of a species}}{\text{Vegatation Cover of all species}} \text{ x } 100\%$$

Biomass

$$\text{Total dry weight} = \frac{\text{Dry weight of the subsample}}{\text{Wet weight of the subsample}} \text{ x Total wet weight}$$

RESULTS AND DISCUSSION

Habitus and genera composition

The study results identified 263 understory species, including herb, liana, and shrubs, within MRNP. Based on the single-plot analysis, the understory composition was predominantly herbs (71%), followed by shrubs (26%), and lianas (3%) (Figure 2). Following a fire, endemic or native species play a significant role in ecosystem recovery and in maintaining understory diversity. Endemic species often have specific adaptations, such as fire resistance and the ability to germinate and regenerate post-fire, enabling them to thrive under such conditions. The presence of native species not only accelerates the rehabilitation process but also helps maintain ecosystem balance by controlling the aggression of alien species that harm the structure of regional vegetation (Afrianto et al. 2020). Grassland formations in the MRNP, as well as in other Indonesian parks such as Bali Barat National Park and Baluran National Park, are generally dominated by Gramineae/Poaceae and their associated herbaceous species, particularly in arid savanna ecosystems (Sutomo and van Etten 2021). In the soil seed banks of Mount Ciremai National Park and Kuningan Botanic Gardens, herbaceous plants were found to dominate over woody plants (Ekasari et al. 2021). Understory plant communities serve as effective ecological indicators to determine forest health, as they provide ecosystem services, such as nutrient cycling, productivity, ecosystem self-regeneration, and organic matter decomposition (Deng et al. 2023).

Based on taxonomical analysis at the genus and species levels, the study location was primarily dominated by the families Poaceae and Asteraceae (Figure 3). Poaceae comprised 20 genera, followed by Asteraceae with 17 genera, Rubiaceae with 7 genera, Lamiaceae with 5 genera, and Fabaceae 4 with genera. The species diversity of members of the Asteraceae was higher than members of Poaceae. While Asteraceae exhibited higher species diversity, individual genera within Poaceae often contained multiple species. Field observations revealed that Asteraceae species formed associations with Poaceae, particularly young plants. These Asteraceae species often act as pioneer species, colonizing grassland areas. This pattern aligns with the understory composition of Lore Lindu National Park, where Asteraceae is also a dominant family (Ramadhanil et al. 2008). The Asteraceae family is recognized as the most prominent family of flowering plants, comprising approximately 1600 genera and 25,000 species worldwide (Rolnik and Olas 2021). Generally, species in the Asteraceae family have historically been used for food and medicine purposes due to their bioactive content and potential applications (Bessada et al. 2015).

Moreover, based on the overall floristic composition data, the understory species identified were primarily pioneer species, suggesting that this ecosystem has not reached its ecological climax and has experienced disturbances in the past. A similar condition was observed in Mount Merapi National Park, where understory species dominated the area as pioneer plants following the 2010 eruption (Afrianto et al. 2020). A study on post-fire vegetation changes in Rimba Panjang revealed that understory increased from 12 species to 17 species plants over eight years (Firdaus et al. 2017). Species from the different successional stages exhibited distinct patterns of trait distribution, and other vital characteristics predicted species turnover during succession (Chai et al. 2016). In the climax ecosystems, vegetation tends to be dense with high humidity, creating conditions less susceptible to fire. In contrast, ecosystems that have not yet climaxed tend to have lower moisture levels, especially in savannas that are directly exposed to sunlight without obstructions. This condition causes the savanna ecosystem in MRNP more vulnerable to fires. Additionally, cattle activity disrupts the grass ecosystem from reaching its climax. Consequently, fire and grazing are recognized as key factors in maintaining grassland ecosystem and preventing its transition to another form (van Steenis et al. 2006).

Species composition

The Fabaceae and Cyperaceae families exhibited disproportionate species richness relative to their number of genera (Figure 4). The Fabaceae family included four genera with nine species, while Cyperaceae comprised a single genus with four species. The genera *Desmodium* and *Cyperus* were particularly species-rich within their respective families. Monk et al. (2000) noted the widespread distribution of *Cyperus* and *Desmodium* in grasslands undergoing a succession process toward community stability. These genera have been also reported to dominate open grazing lands in *Chapra* (Kumari and Jha 2016). *Themeda triandra* (Poaceae) emerged as the most dominant grass species on the Sembalun hiking trail (Figure 5), which is a popular tourist destination heavily visited by visitors (Ayuni and Priyana 2019). *Themeda triandra* has spread widely to almost all regions in Australia and is estimated to have originated in the Asian savanna approximately 1.5 million years ago (Dunning et al. 2017).

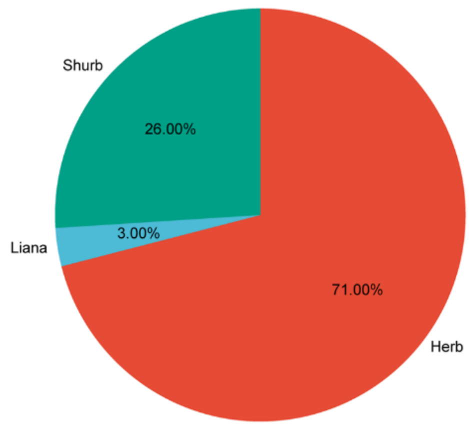

Figure 2. Proportion of vegetation habitus in the MRNP, West Nusa Tenggara Province, Indonesia

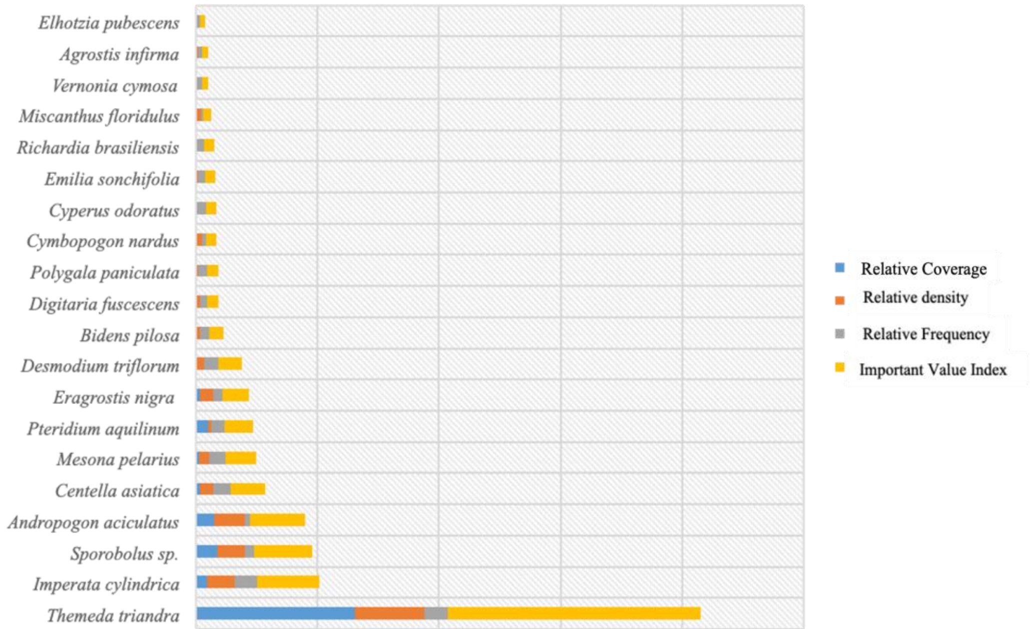

Figure 3. Results of vegetation analysis in the MRNP, West Nusa Tenggara Province, Indonesia

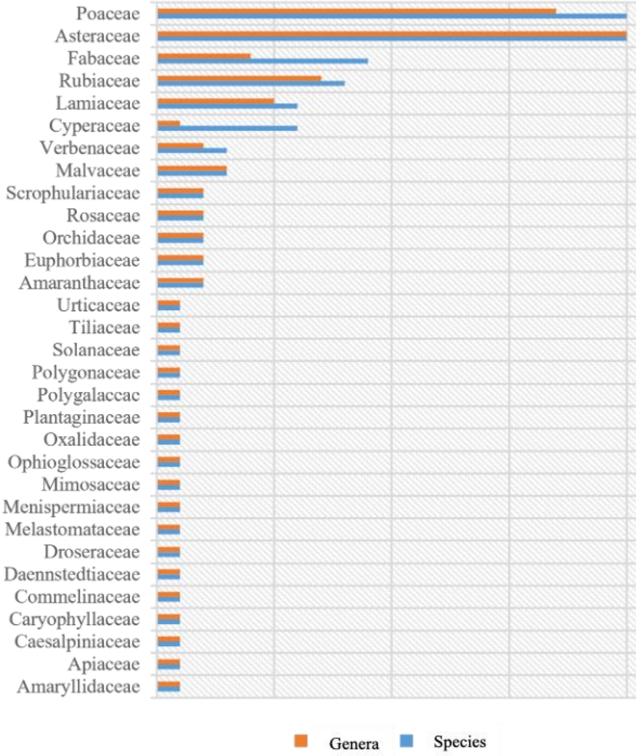

Figure 4. Proportion of the number of genera and species in the MRNP, West Nusa Tenggara Province, Indonesia

Additionally, the awn length and average annual temperature have a positive relationship (Cavanagh et al. 2024). In the short term, the dominance of alien species can reduce the variety of native species and modify ecosystem processes (Bartha et al. 2014). In the long term, this dominance can lead to continuous changes in community structure and ecosystem function, diminishing the ecosystem's stability against disruption and its capacity to sustain critical ecological processes (Heard et al. 2012). The important value index (IVI) of *T. triandra* was the highest and significantly different from other subdominant Poaceae types such as *Imperata cylindrica*, *Sporobolus* sp., and *Chrysopogon aciculatus*. This finding indicates an unhealthy grass community, suggesting historical disturbances in the past. Based on interviews with MRNP staff, forest fires frequently occur on Mount Rinjani due to human activities, particularly the deliberate burning of grasslands to attract deer to new growth areas. Similar conditions have been observed in Sumbawa, Timor, and Sumba, where grass is burned to provide fresh grass for wildlife and livestock.

Field observations indicate that *T. triandra*, *I. cylindrica*, *Sporobolus* sp., and *Capillipedium parviflorum* are the most preferred grass species for cattle grazing in the MRNP. Continuous grazing by cattle causes the grass to regenerate, leading to persistent ecological disturbance in the grassland. Therefore, efforts are needed to regulate the scale of grazing and implement adaptive management to optimize its benefits (Mudongo et al. 2016). Grazing activities in understory vegetation with palatable native species can combine conservation efforts with production integration methods that reduce the incidence of burning (Herrera et al. 2021). According to van Steenis (2010), in climax mixed vegetation areas, there is insufficient fuel load to sustain widespread fires, even if ignited. Thus, promoting the formation of climax vegetation can be an effective strategy to mitigate fire risks.

The grasses identified in this study can be categorized into two groups: tall grasses and carpet grasses (Figure 6). Tall grasses include species and shrubs that reach height exceeding 50 cm, while carpet grasses encompass species that do not grow taller than 7 cm. The tall grasses and their associations include *T. triandra*, *I. cylindrica*, *Sporobolus* sp., *Agrostis inflata*, *Miscanthus floridulus*, *E. nigra*, *Elsholtzia pubescens*, *Inula cappa*, *Chromolaena odorata*, and *Cymbopogon nardus*. Understory species classified as carpet grasses and their associations include *C. aciculatus*, *Digitaria nuda*, *D. fuscescens*, *Eleusine indica*, *Centella asiatica*, *Richardia brasiliensis*, and *Desmodium triflorum*. Savannas in MRNP experience prolonged drought periods every year. The term “humid savanna” refers to areas with a dry period of 2.5-5 months, while “dry savanna” refers to areas with a dry period of 5-7.5 months. Savanna types in this region include: i. savanna covered with grass and bushes (non-canopy); ii. tree/shrub savanna, characterized by trees and bushes with a canopy of less than 2%; iii. wooded savanna, with a tree canopy between 2 and 15%; iv. forested savanna, containing trees with canopy cover of 20-30%; v. open forest, a savanna covered by trees with canopy cover of 50% (Mistry and Beradi 2014).

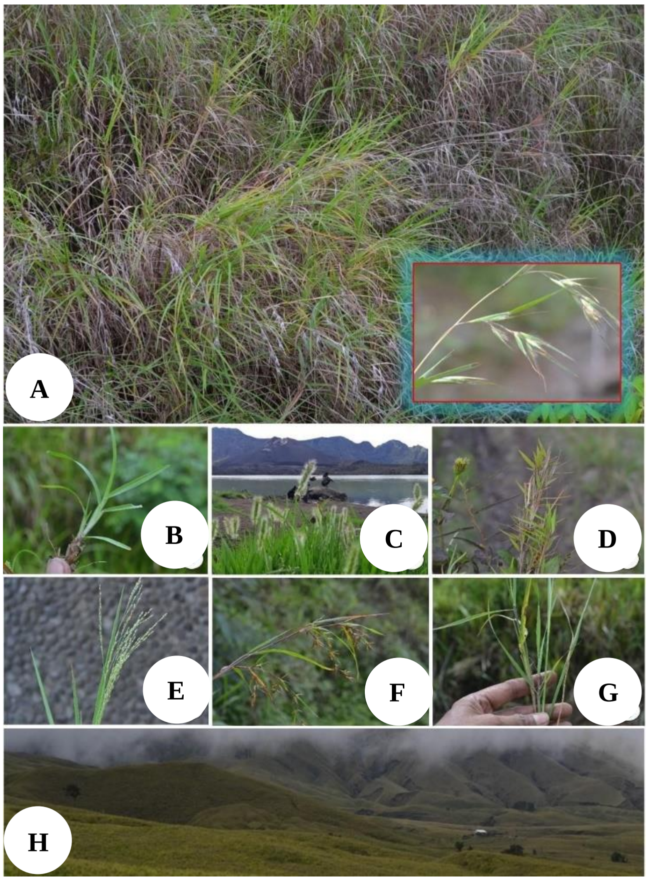

Figure 5. A. *Themeda triandra* (Poaceae); B. *Chrysopogon aciculatus* (Poaceae); C. *Polypogon monspeliensis* (Poaceae); D. *Pogonatherum paniceum* (Poaceae); E. *Panicum repens* (Poaceae); F. *Apluda mutica* (Poaceae); G. *C. parviflorum* (Poaceae); H. the expanse of grasslands in the MRNP

Figure 6. Community of carpet and tall grasses in the MRNP: A. Carpet grass; and B. Tall grass

Savanna ecosystem is present in several conservation areas, especially national parks such as Alas Purwo, Bromo Tengger Semeru, Baluran, West Bali, Gunung Rinjani, Komodo, Kelimutu, and Wasur National Park. National parks are natural conservation areas with original ecosystems managed through a zoning system and utilized for research, scientific and education purposes and some extent of tourism and recreation activities. The savanna in national parks serves as a unique attraction. Managing ecosystem balance by preventing erosion, producing organic material, and serving as a food source for various wildlife species, is vital for savanna vegetation. Natural grasslands function most effectively in decreasing erosion and runoff during extended precipitation events (72 hours) (Hu et al. 2023). Additionally, fire activity significantly affects below-ground ecosystem processes, causing fire-driven soil carbon (C) losses. These losses are often presumed to arise primarily in the upper soil layers because the duplicated explosion of above-ground biomass limits organic matter intake into the surface soil (Pellegrini et al. 2020). This is due to the short-lived nature of the roots of savanna vegetation, resulting in a buildup of decomposing organic matter in the soil.

Biomass

The result showed that the dry biomass can reach a thickness of 10 cm over two years, with a potential of 5.7 Mg ha^{-1}. This biomass significantly increases the likelihood of fire ignition. The composition and structure of the grasses are affected by the release of carbon stored in the biomass of understory plants during processes like decomposition or fire. The dry plants or litter with a thickness of about 10 cm can produce heat resulted from fermentation which becomes a fire source. This litter can also burn due to sunlight reflected in a focused manner by glass bottle waste and aluminum beverage cans left by visitors. The hazard analysis indicates that visitor activities are also considered the highest risk in MRNP (Jasthin et al. 2024). In addition, the litter can also become flammable due to periodic lightning strikes (Nampak et al. 2021). Previous research has documented a range of understory biomass values across various regions. In the temperate regions of the Himalayas, biomass ranged from 2.4 to 7.64 Mg ha^{-1} (Wani et al. 2016). Ahmad et al. (2018) recorded biomass values ranging from 1.1 to 2.6 Mg ha^{-1} in Kumrat Valley, Pakistan, while forests in the eastern Himalayas exhibited biomass values between 1.95 and 3.77 Mg ha^{-1} (Tashi et al. 2017). Ali et al. (2019) documented understory biomass values of 1.9 to 2.1 Mg ha^{-1} in Hubei province, Central China. In Himalayan forests, Dar and Sundarapandian (2015) observed biomass ranging from 0.16 to 2.36 Mg ha^{-1}. Haq et al. (2023) reported an average understory carbon stock of 2.79 Mg C ha^{-1} in the forests of Jammu and Kashmir. In the northwestern Himalayas, biomass values were recorded between 4.28 and 11.08 Mg ha^{-1} (Banday et al. 2018). Amir et al. (2018) noted an average understory carbon stock of 0.86 Mg C ha^{-1} in the *Pinus* forests of Pakistan. Mannan et al. (2018) measured carbon stocks in Magallah Hills National Park, Pakistan, with understory values of 2.3±0.27 Mg C ha^{-1} and 1.81±0.41 Mg C ha^{-1}. In rubber monoculture systems, understory biomass was estimated at 0.94 Mg ha^{-1}; in rubber agroforestry systems, the biomass was slightly lower at 0.84 Mg ha^{-1} (Muhdi et al. 2020).

In conclusion, the presence of understory plant communities in Mount Rinjani National Park can serve as effective ecological indicators for assessing forest health based on the number of species present. The ecosystem conditions are categorized as not yet reaching climax. Findings on the dominance of species, such as Poaceae and Asteraceae, can inform strategies for vegetation management, invasive species control, and planning for forest fire prevention and mitigation. Information on biomass values and the dominance of certain plant species can assist in designing forest fire prevention strategies. These findings also provide a foundation for further research on vegetation dynamics in various national parks and other conservation areas. Additional research can offer deeper insights into the interactions between species and the impacts of environmental changes on the structure of understory plant communities. This study is only limited to addressing understory vegetation and biomass. Future research will address its major community types and environmental, edaphic, and climatic variables to provide a more comprehensive understanding and context for the findings.

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